Listing of Claims

1-15. (Cancelled).

16. (Currently Amended) The apparatus set forth in claim ~~15~~ 58 wherein said adaptive filter circuit comprises a microprocessor.

17. (Original) The apparatus set forth in claim 16 wherein said subtracter circuit comprises said microprocessor.

18-30. (Cancelled).

31. (Currently Amended) The method as set forth in claim ~~30~~ 60 wherein said multiple upstream channels comprise a first channel and a second channel.

32-50. (Cancelled)

51. (Currently Amended) The apparatus as set forth in claim ~~50~~ 62 further comprising:

a difference circuit coupled to an output of said finite impulse response filter for coupling to said downstream path for generating an error signal representing the difference between a signal on said downstream path representing sound at said second location and said estimate.

52. (Previously Presented) The apparatus as set forth in claim 51 wherein said finite impulse response filter comprises:

multiple finite impulse response circuits for each of said upstream channels for generating an echo response that models an echo response corresponding to an echo path at said second location from said corresponding upstream channel to said downstream channel.

53. (New) A method of adaptively filtering a signal transmitted over a channel, said signal containing an input signal and multiple echo responses, said multiple echo responses to be adaptively filtered, said method comprising the steps of:

generating an estimate of an echo response corresponding to each of said multiple echo responses, wherein each of said estimates is generated via the equation:

$$\underline{\hat{\mathrm{h}}}(m) = \underline{\hat{\mathrm{h}}}(m-1) + (1-\lambda_f)\,\mathrm{S}^{-1}(m)\,\mathrm{D}^H(m)\,\underline{\mathrm{e}}(m)$$

where

$$\underline{\mathrm{e}}(m) = \underline{\mathrm{y}}(m) - \mathrm{GD}(m)\,\underline{\hat{\mathrm{h}}}(m-1)$$, and

$$\begin{aligned}\mathrm{S}(m) &= (1-\lambda_f)\sum_{p=0}^{m}\lambda_f^{m-p}\,\mathrm{D}^H(p)\,\mathrm{GD}(p)\\ &= \lambda_f\,\mathrm{S}(m-1) + (1-\lambda_f)\,\mathrm{D}^H(m)\,\mathrm{GD}(m)\end{aligned}$$;

wherein

$\underline{\underline{\hat{\mathrm{h}}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix};$$

generating a sum of said estimates; and

generating an error signal representing the difference between said signal and said sum of said estimates;

wherein said estimates are generated using a frequency domain recursive least squares algorithm.

54. (New) A method of adaptively filtering a signal transmitted over a channel, said signal containing an input signal and multiple echo responses, said multiple echo responses to be adaptively filtered, said method comprising the steps of:

generating an estimate of an echo response corresponding to each of said multiple echo responses, wherein each of said estimates is generated via the equation:

$$\underline{\hat{h}}(m) = \underline{\hat{h}}(m-1) + \mu_u S_u^{-1}(m) D^H(m) \underline{e}(m).$$

where

$$\underline{e}(m) = \underline{y}(m) - \mathbf{GD}(m) \underline{\hat{h}}(m-1)$$, and

$$S_u(m) = \lambda_f S_u(m-1) + (1-\lambda_f) D^H(m) D(m)$$:

wherein

$\underline{\underline{\hat{h}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

$\boldsymbol{\lambda} f$= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix}$$;

generating a sum of said estimates; and

generating an error signal representing the difference between said signal and said sum of said estimates;

wherein said estimates are generated using a frequency domain recursive least squares algorithm.

55. (New) A method for transmitting an input signal over a channel in a multiple channel communication apparatus where said input signal generates multiple echo responses and results in an output signal, wherein said multiple echo responses are adaptively filtered, said method comprising the steps of:

transmitting said signal over a channel, wherein said input signal generates at least first and second echo responses;

generating an estimate of an echo response corresponding to each of said first and second echo responses, wherein each of said estimates is generated via the equation:

$$\underline{\hat{\mathrm{h}}}(m) = \underline{\hat{\mathrm{h}}}(m-1) + (1-\lambda_f)\,\mathrm{S}^{-1}(m)\,\mathrm{D}^H(m)\,\underline{\mathrm{e}}(m)$$

where

$$\underline{\mathrm{e}}(m) = \underline{\mathrm{y}}(m) - \mathrm{GD}(m)\,\underline{\hat{\mathrm{h}}}(m-1)$$, and

$$\begin{aligned}\mathrm{S}(m) &= (1-\lambda_f)\sum_{p=0}^{m} \lambda_f^{m-p}\,\mathrm{D}^H(p)\,\mathrm{GD}(p) \\ &= \lambda_f\,\mathrm{S}(m-1) + (1-\lambda_f)\,\mathrm{D}^H(m)\,\mathrm{GD}(m)\end{aligned}$$;

wherein

$\underline{\underline{\hat{\mathrm{h}}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf = an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix};$$

generating a sum of said estimates; and

generating an error signal representing the difference between said signal and sum of said estimates;

wherein said estimate are generated using a frequency domain recursive least squares algorithm.

56. (New) A method for transmitting an input signal over a channel in a multiple channel communication apparatus where said input signal generates multiple echo responses and results in an output signal, wherein said multiple echo responses are adaptively filtered, said method comprising the steps of:

transmitting said signal over a channel, wherein said input signal generates at least first and second echo responses;

generating an estimate of an echo response corresponding to each of said first and second echo responses, wherein each of said estimates is generated via the equation:

$$\underline{\hat{\mathrm{h}}}(m) = \underline{\hat{\mathrm{h}}}(m-1) + \mu_u \mathrm{S}_u^{-1}(m)\, \mathrm{D}^H(m)\, \underline{\mathrm{e}}(m).$$

where

$$\underline{\mathrm{e}}(m) = \underline{\mathrm{y}}(m) - \mathrm{GD}(m)\, \underline{\hat{\mathrm{h}}}(m-1)$$, and

$$\mathrm{S}_u(m) = \lambda_f\, \mathrm{S}_u(m-1) + (1-\lambda_f)\, \mathrm{D}^H(m)\, \mathrm{D}(m)$$;

wherein

$\underline{\underline{\hat{\mathrm{h}}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix}$$

generating a sum of said estimates; and

generating an error signal representing the difference between said signal and sum of said estimates;

wherein said estimate are generated using a frequency domain recursive least squares algorithm.

57. (Previously Presented) An apparatus for transmitting an input signal over a channel in a multiple channel communication apparatus, said apparatus comprising:

a transmitter for generating an input data signal for transmission via a communication channel, wherein said input data signal generates multiple echo responses on said channel and results in an output data signal, wherein said multiple echo responses are to be adaptively filtered;

an adaptive filter circuit for generating an estimate of an echo response corresponding to each of said multiple echo responses, wherein each of said estimates is generated via the equation:

$$\underline{\hat{\mathrm{h}}}(m) = \underline{\hat{\mathrm{h}}}(m-1) + (1-\lambda_f)\,\mathrm{S}^{-1}(m)\,\mathrm{D}^{H}(m)\,\underline{\mathrm{e}}(m)$$

where

$$\underline{\mathrm{e}}(m) = \underline{\mathrm{y}}(m) - \mathrm{GD}(m)\,\underline{\hat{\mathrm{h}}}(m-1)$$

, and

$$S(m) = (1-\lambda_f)\sum_{p=0}^{m} \lambda_f^{m-p} D^H(p)\,GD(p)$$
$$= \lambda_f S(m-1) + (1-\lambda_f)\, D^H(m)\,GD(m)$$
:

wherein

$\underline{\underline{\hat{h}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix}$$; and

a subtracter circuit for generating an error signal representing the difference between said output data signal and a sum of said estimates;

wherein said estimates are generated using a frequency domain recursive least squares algorithm.

58. (New) An apparatus for transmitting an input signal over a channel in a multiple channel communication apparatus, said apparatus comprising:

a transmitter for generating an input data signal for transmission via a communication channel, wherein said input data signal generates multiple echo responses on said channel and results in an output data signal, wherein said multiple echo responses are to be adaptively filtered;

an adaptive filter circuit for generating an estimate of an echo response corresponding to each of said multiple echo responses, wherein each of said estimates is generated via the equation:

$$\underline{\hat{\mathrm{h}}}(m) = \underline{\hat{\mathrm{h}}}(m-1) + \mu_u \mathrm{S}_u^{-1}(m)\,\mathrm{D}^H(m)\,\underline{\mathrm{e}}(m).$$

where

$$\underline{\mathrm{e}}(m) = \underline{\mathrm{y}}(m) - \mathrm{GD}(m)\,\underline{\hat{\mathrm{h}}}(m-1)$$

, and

$$\mathrm{S}_u(m) = \lambda_f\,\mathrm{S}_u(m-1) + (1-\lambda_f)\,\mathrm{D}^H(m)\,\mathrm{D}(m)$$

:

wherein

$\underline{\underline{\hat{\mathrm{h}}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix}$$; and

a subtracter circuit for generating an error signal representing the difference between said output data signal and a sum of said estimates;

wherein said estimates are generated using a frequency domain recursive least squares algorithm.

59. (New) A method of canceling distortion in a communication system having multiple upstream transmission channels from a first location to a second location and at least one downstream transmission channel from said second location to said first location, said method comprising the steps of:

developing an estimated echo response corresponding to each of said multiple upstream channels that models an interference path at said second location from said corresponding upstream channel to said downstream channel, wherein each of said estimated echo responses is generated via the equation:

$$\underline{\hat{\mathrm{h}}}(m) = \underline{\hat{\mathrm{h}}}(m-1) + (1-\lambda_f)\,\mathrm{S}^{-1}(m)\,\mathrm{D}^H(m)\,\underline{\mathrm{e}}(m)$$

where

$$\underline{\mathrm{e}}(m) = \underline{\mathrm{y}}(m) - \mathrm{GD}(m)\,\underline{\hat{\mathrm{h}}}(m-1)$$, and

$$\begin{aligned} S(m) &= (1-\lambda_f)\sum_{p=0}^{m} \lambda_f^{m-p} D^H(p)\, GD(p) \\ &= \lambda_f S(m-1) + (1-\lambda_f)\, D^H(m)\, GD(m) \end{aligned}$$
;

wherein

$\hat{\underline{\underline{h}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix}$$
;

convolving each of said estimated echo responses with a signal on the corresponding one of said upstream channels to generate an estimate corresponding to each of said upstream channels; and

summing each of said estimates;

wherein said estimate is generated using a frequency domain recursive least squares algorithm.

60. (New) A method of canceling distortion in a communication system having multiple upstream transmission channels from a first location to a second location and at least one downstream transmission channel from said second location to said first location, said method comprising the steps of:

developing an estimated echo response corresponding to each of said multiple upstream channels that models an interference path at said second location from said corresponding upstream channel to said downstream channel, wherein each of said estimated echo responses is generated via the equation:

$$\underline{\hat{\mathrm{h}}}(m) = \underline{\hat{\mathrm{h}}}(m-1) + \mu_u \mathrm{S}_u^{-1}(m)\,\mathrm{D}^H(m)\,\underline{\mathrm{e}}(m).$$

where

and

$$\mathrm{S}_u(m) = \lambda_f\,\mathrm{S}_u(m-1) + (1-\lambda_f)\,\mathrm{D}^H(m)\,\mathrm{D}(m)$$

$$\mathrm{S}_u(m) = \lambda_f\,\mathrm{S}_u(m-1) + (1-\lambda_f)\,\mathrm{D}^H(m)\,\mathrm{D}(m)$$

:

wherein

$\underline{\underline{\hat{\mathrm{h}}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix} \qquad ;$$

convolving each of said estimated echo responses with a signal on the corresponding one of said upstream channels to generate an estimate corresponding to each of said upstream channels; and

summing each of said estimates;

wherein said estimate is generated using a frequency domain recursive least squares algorithm.

61. (New) An apparatus for performing echo cancellation in a multi-channel teleconferencing system comprising at least first and second upstream electrical paths between a first location and a second location for transmitting acoustic signals from said first location to said second location and at least one downstream electrical path between said second location and said first location for transmitting acoustic signals from said second location to said first location, said apparatus comprising;

at least one non-linear transformation module for coupling within each of one or more of said upstream paths;

a finite impulse response filter for coupling between said upstream paths and said downstream path for generating an estimate of an echo response corresponding to echo paths at said second location coupled between each of said multiple upstream channels and said downstream channel in which said estimate is generated using a frequency domain recursive least squares algorithm, wherein each of said estimates is generated via the equation:

$$\hat{\underline{\mathrm{h}}}(m) = \hat{\underline{\mathrm{h}}}(m-1) + (1-\lambda_f)\,\mathrm{S}^{-1}(m)\,\mathrm{D}^H(m)\,\underline{\mathrm{e}}(m)$$

where

$$\underline{\mathrm{e}}(m) = \underline{\mathrm{y}}(m) - \mathrm{GD}(m)\,\hat{\underline{\mathrm{h}}}(m-1)$$

, and

$$\begin{aligned}\mathrm{S}(m) &= (1-\lambda_f)\sum_{p=0}^{m}\lambda_f^{m-p}\,\mathrm{D}^H(p)\,\mathrm{GD}(p)\\ &= \lambda_f\,\mathrm{S}(m-1) + (1-\lambda_f)\,\mathrm{D}^H(m)\,\mathrm{GD}(m)\end{aligned}$$

:

wherein

$\hat{\underline{\underline{\mathrm{h}}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix}$$

.

62. (New) An apparatus for performing echo cancellation in a multi-channel teleconferencing system comprising at least first and second upstream electrical paths between a first location and a second location for transmitting acoustic signals from said first location to said second location and at least one downstream electrical path between said second location and said first location for transmitting acoustic signals from said second location to said first location, said apparatus comprising;

at least one non-linear transformation module for coupling within each of one or more of said upstream paths;

a finite impulse response filter for coupling between said upstream paths and said downstream path for generating an estimate of an echo response corresponding to echo paths at said second location coupled between each of said multiple upstream channels and said downstream channel in which said estimate is generated using a frequency domain recursive least squares algorithm, wherein each of said estimates is generated via the equation:

$$\underline{\hat{\mathbf{h}}}(m) = \underline{\hat{\mathbf{h}}}(m-1) + \mu_u \mathbf{S}_u^{-1}(m)\mathbf{D}^H(m)\underline{\mathbf{e}}(m).$$

where

$$\underline{\mathrm{e}}(m) = \underline{\mathrm{y}}(m) - \mathrm{GD}(m)\hat{\underline{\mathrm{h}}}(m-1)$$, and

$$\mathrm{S}_u(m) = \lambda_f \mathrm{S}_u(m-1) + (1-\lambda_f)\,\mathrm{D}^H(m)\,\mathrm{D}(m)$$;

wherein

$\hat{\underline{\underline{\mathrm{h}}}}$ = the frequency domain estimate of the impulse response;

m = a block time index;

λf= an experimental forgetting factor in the frequency domain;

D = a diagonal matrix whose elements are the discrete Fourier transform of the first column of the circulant matrix;

^{H} = conjugate transpose;

e = frequency domain error signal;

y = channel output signal;

G = $F^{-1}WF$;

F = the Fourier matrix; and

$$W = \begin{bmatrix} 0_{LxL} & O_{LxL} \\ 0_{LxL} & I_{LxL} \end{bmatrix}$$.